GL-TR-90-0088

Digisonde at Sondrestrom to Monitor the Ionospheric Polar Cap and Cusp Region

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January 1990

Scientific Report No. 21

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AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1990	Scientific Report No. 21

4. TITLE AND SUBTITLE
Digisonde at Sondrestrom to Monitor the Ionospheric Polar Cap and Cusp Region

5. FUNDING NUMBERS
PE 62101F
PR 4643 TA 10 WU AC

Contract F19628-87-C-0003

6. AUTHOR(S)
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Bodo W. Reinisch
David F. Kitrosser

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Lowell
Center for Atmospheric Research
450 Aiken Street
Lowell, MA 01854

8. PERFORMING ORGANIZATION REPORT NUMBER
ULRF-463/CAR

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Geophysics Laboratory
Hanscom AFB, MA 01731-5000

NorthWest Res. Assoc.
P. O. Box 3027
Bellevue, WA 98009

Contract Manager: Antonio Quesada/LIS

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
GL-TR-90-0088

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

deg

12b. DISTRIBUTION CODE

deg

13. ABSTRACT (Maximum 200 words)

In July 1989, the Air Force meridional chain of Digisondes ~~(Reinisch, 1986)~~ was completed by the installation of a system in Sondrestromfjord, Greenland (66.98 N, 50.94 W). In this report we describe the Sondrestrom site and instrument, and the relationship between Sondrestrom and the other AF sites. We also establish the importance of this site by describing its geophysically unique features. Finally, some of the first measurements from Sondrestrom ~~will be~~ are presented, and interpreted in terms of high latitude features.

Keywords; Geomagnetism; Plasmas physics drift, Magnetosphere

14. SUBJECT TERMS
Ionosphere; polar cap; ionosondes, (EDC) cusp, plasma drift.

15. NUMBER OF PAGES
42

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

1.0 INTRODUCTION

In July 1989, the Air Force meridional chain of Digisondes [Reinisch, 1986] was completed by the installation of a system in Sondrestromfjord, Greenland (66.98°N, 50.94°W). In this report we describe the Sondrestrom site and instrument, and the relationship between Sondrestrom and the other AF sites. We also establish the importance of this site by describing its geophysically unique features. Finally, some of the first measurements from Sondrestrom will be presented, and interpreted in terms of high latitude features.

In order to describe the scientific applications of the Sondrestrom data, it is essential to discuss various coordinate systems. Several of these have been discussed by Wickwar et al. [1984] in relation to the incoherent scatter radar located there. The simplest coordinate system involves the geographic location, local time, and, on occasion, solar zenith angles. However, many high-latitude processes are greatly affected by the configuration of the magnetic field. Because of the importance and complexity of the magnetic field at Sondrestrom, it requires some discussion and a careful definition of magnetic coordinates.

Figure 1 shows the Digisonde location in terms of geographic and geomagnetic (invariant) coordinates. The invariant system was developed by McIlwain [1961, 1966]. The invariant coordinates in Figure 1 are derived from the International Geomagnetic Reference Field, IGRF (1980) model [IAGA, 1981] updated to 1983 and calculated for 350-km altitude. Sondrestrom is at Λ = 74.8° (invariant). The plane that is perpendicular to the lines of invariant latitude Λ, i.e. to the magnetic north, is at -27° geographic azimuth.

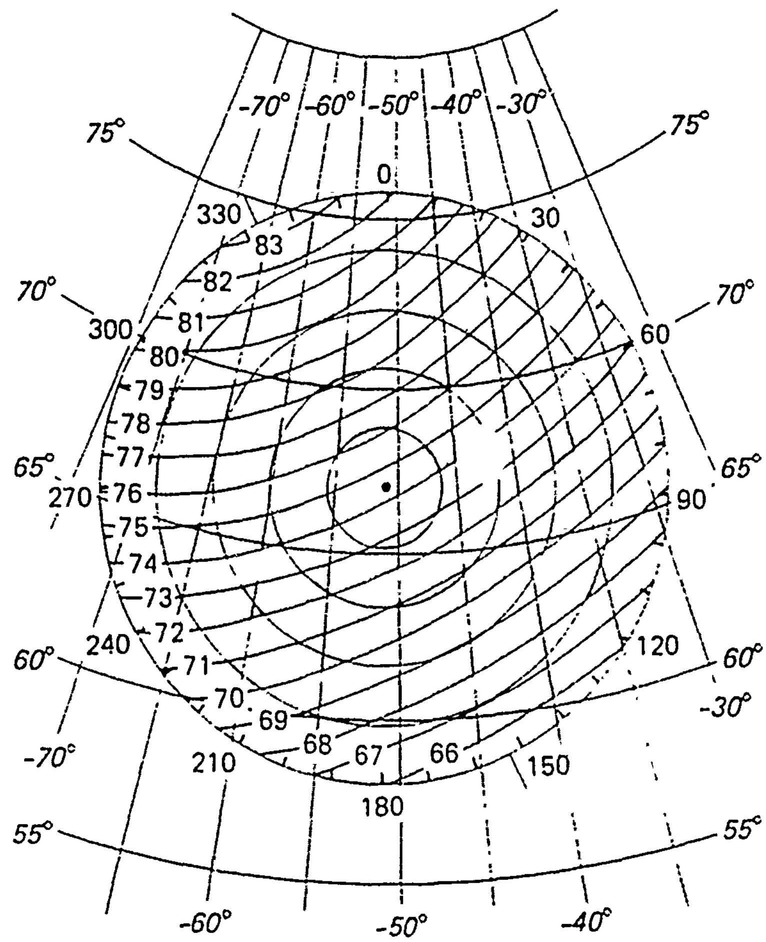


Figure 1. Geographic and geomagnetic locations of Sondrestrom: longitude and latitude, azimuth and distance (200 km intervals), invariant latitude from the IGRF (1980) model for 1983 and 350 km altitude.

Magnetic declination is commonly used to define "magnetic north." The magnetic declination is defined as the azimuth of a plane passing through the local magnetic field line and the local zenith, and is the direction in which a compass needle points. At Sondrestrom this is -41.2° (i.e. West relative to geographic North). Thus "magnetic north," and the magnetic declination are not the same. If the magnetic field were a centered dipole, then the two azimuths would be the same. If it were an offset dipole, then there would be only one plane for which the two azimuths would agree. Elsewhere, the magnetic meridian plane would be tilted with respect to the local zenith. For the real field, these parameters should rarely agree. At Sondrestrom, a tilt of only 2.1° is needed to account for the 14° difference between magnetic north and the magnetic declination.

Two other magnetic coordinate systems are also in common use: i) The apex coordinate system was developed by Van Zandt et al. [1972a, b]. It was developed because the existing coordinate systems did not satisfactorily organize F2-layer data obtained from a range of heights in low and middle latitudes. Figure 2 illustrates the variation of apex and invariant coordinates with geographic coordinates. At the higher latitudes, of relevance to Sondrestrom, the two sets of contours are virtually coincident. (λ_A for Sondrestrom is 74.8°, apex longitude is 42.5°E at 300 km.) ii) Corrected geomagnetic coordinates are used throughout this report when discussing Digisonde data.

Corrected geomagnetic coordinates [Maynard, 1960; Hakura, 1965] are in most respects very similar to invariant and apex coordinates [Van Zandt et al., 1972]. However, the latitude is defined for the surface of the earth, and the latitude of points at other heights is defined to be the same as at the surface. The CG coordinates are not defined for latitudes less than 30°. The CG latitude for Sondrestrom is 75°. Note that corrected magnetic north (i.e. the plane perpendicular to lines of constant CG-latitude) is at

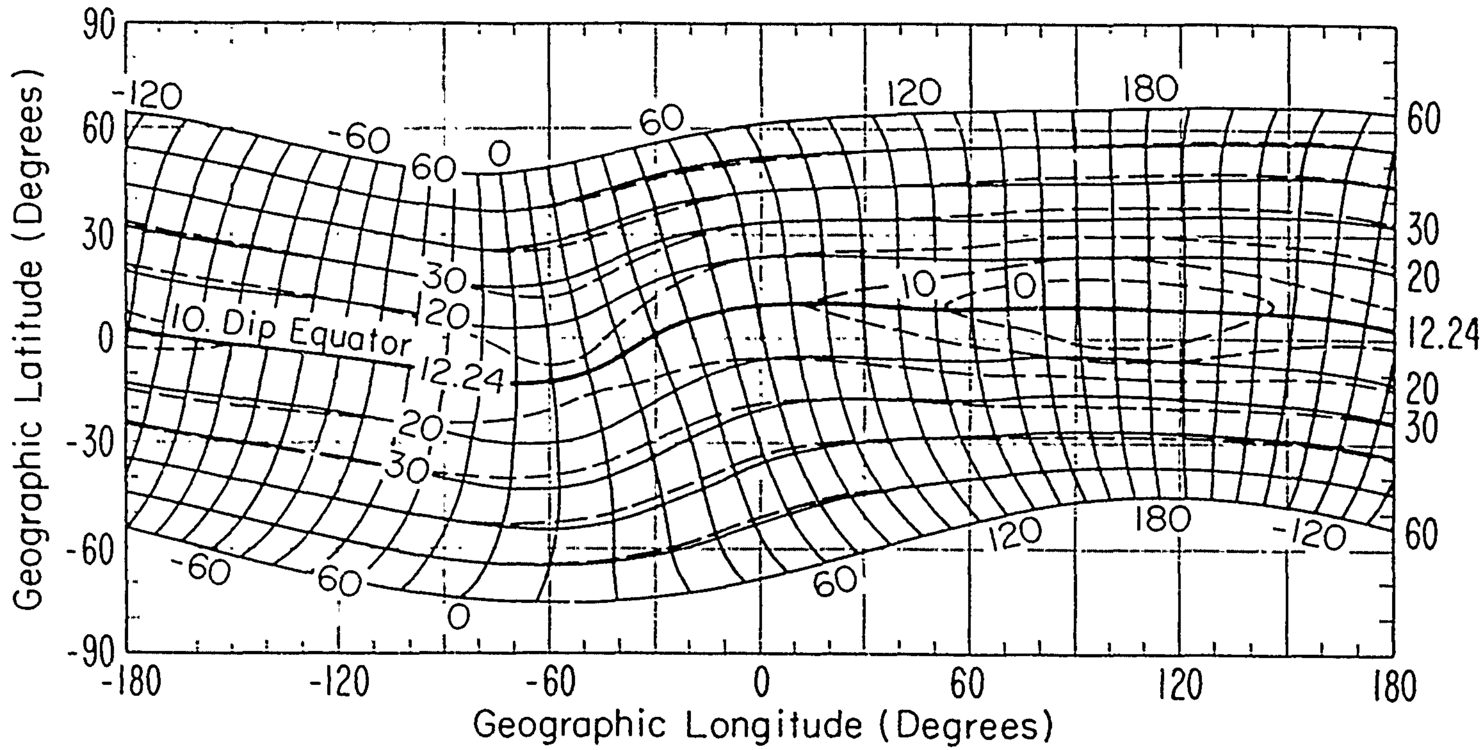


Figure 2. A contour map at 300 km height of apex latitude, apex longitude (solid lines), and L latitude (dotted lines). The contour interval is 10°. The dip equator is the heavy solid line labeled with the apex latitude of 12.24°; apex longitude contours are labeled above and below (after VanZandt et al., 1972).

-19° geographic azimuth (compared with -27° for invariant coordinates).

To complement magnetic latitude in ordering the data, it is necessary to have an appropriate time parameter. The universal time (UT) and local standard time at Sondrestrom (midnight standard time is 0300 UT) are commonly used. Midnight local solar time is 0324 UT at Sondrestrom and, referring to 350-km altitude in Figure 3, it varies with Λ from 35 min earlier at 64° to 50 min later at 82°. Similarly, midnight magnetic local time (MLT) is 0157 UT at Sondrestrom at equinox and varies from 14 min earlier at 64° to 30 min later at 82°. That this latter variation is not zero indicates that the plane at -27° is not exactly along the magnetic meridian, and that the meridian itself is not a plane.

The MLT is calculated according to a computer code developed by M. J. Baron and A. R. Hessing [SRI International, unpublished manuscript, 1982]. The geomagnetic field line is traced from the observed point until it intercepts the latitude of the subsolar point δ at geographic longitude λ_δ. The UT of magnetic midnight, expressed in degrees, is 360° - λ_δ and each magnetic hour has 60 min. Magnetic midnight varies during the year as the subsolar latitude, or solar declination, varies. At Sondrestrom it is 25 min later at the winter solstice and 25 min earlier at the summer solstice, than at the equinoxes. All points along the same field line, as represented by the magnetic field model, will have the same MLT.

Corrected geomagnetic local time differs from the magnetic local time defined above. The CG local midnight meridian is defined as the magnetic meridian which goes through the antipode of the subsolar point. One hour of CGLT corresponds to 15° of magnetic longitude. The CGLT system is briefly discussed in connection with Figure 5.

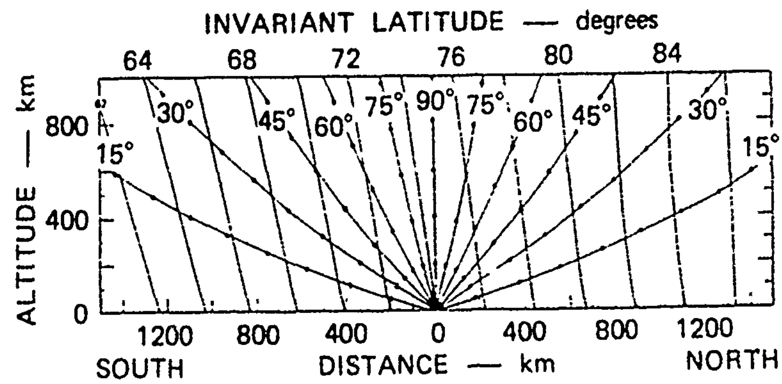


Figure 3. Approximate magnetic meridian plane at -27° azimuth: distance and altitude, elevation and range (200 km intervals), invariant latitude.

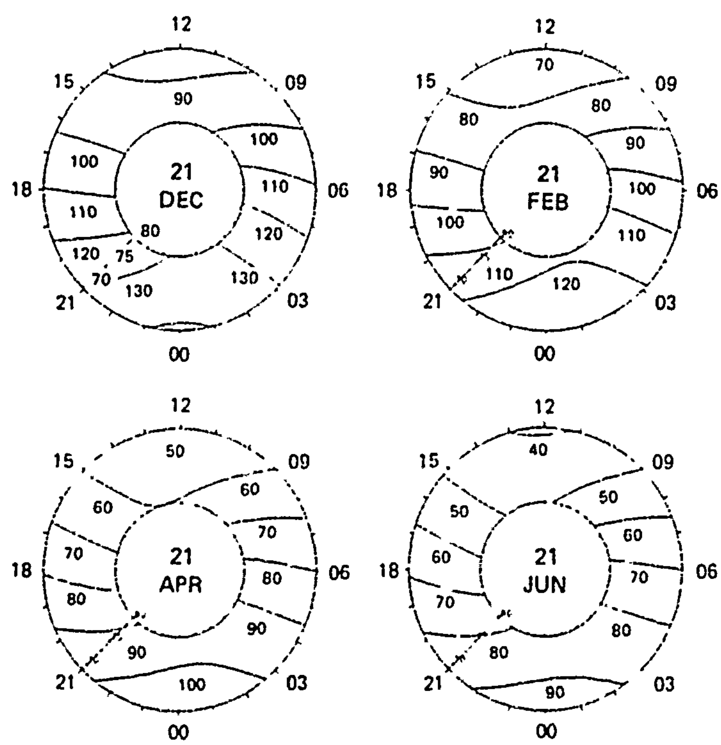


Figure 4. Solar zenith angles over the radar field of view. The coordinates are invariant latitude, from 69° to 80°, at an azimuth of -27° and local standard time (add 3 hr for UT).

Because both Λ and MLT depend on the magnetic field, which is subject to secular variation; the constancy of these values has been examined. For 350 km above Sondrestrom, the IGRF model shows a reduction in Λ of 0.05° per year and an increase in the UT of magnetic midnight of 23 s per year. These extrapolated rates of change are small enough that for now, they can be neglected.

In addition to knowing what locations and times to associate with the data, knowing whether the region probed was sunlit is important. Because the Digisonde is located just poleward of the arctic circle, the solar zenith angle (SZA) is always greater than 90° at the winter solstice and always less than 90° at the summer solstice. In Figure 4, SZA information is displayed as a function of standard time at Sondrestrom and invariant latitude along the -27° azimuth. The sunlit region progresses from slightly south of the radar at noon at winter solstice to covering all but the southern part of the sky at midnight at summer solstice.

The Digisonde located in Sondrestrom is an important link in the meridional chain of high latitude instruments operated by the Air Force. The other stations in the chain are Qaanaaq, Goose Bay and Argentia. Figure 5 shows the locations of these stations in corrected geomagnetic coordinates and corrected magnetic local time. A Digisonde owned by the University of Lowell is colocated with an incoherent scatter radar at Millstone Hill, which is also shown for reference. There is no Digisonde at the EISCAT radar site. Since magnetic local time changes with season with respect to UT, three UT scales are depicted near the center of the figure for June, March/September, and December [Whalen, 1970].

The auroral oval superimposed on Figure 5 represents a moderate magnetic activity level (Q = 3) for magnetic midnight at both Qaanaaq and Sondrestrom (02 UT in October). At 02 UT, the EISCAT radar is in the morning sector and the Millstone radar is in the late evening sector.

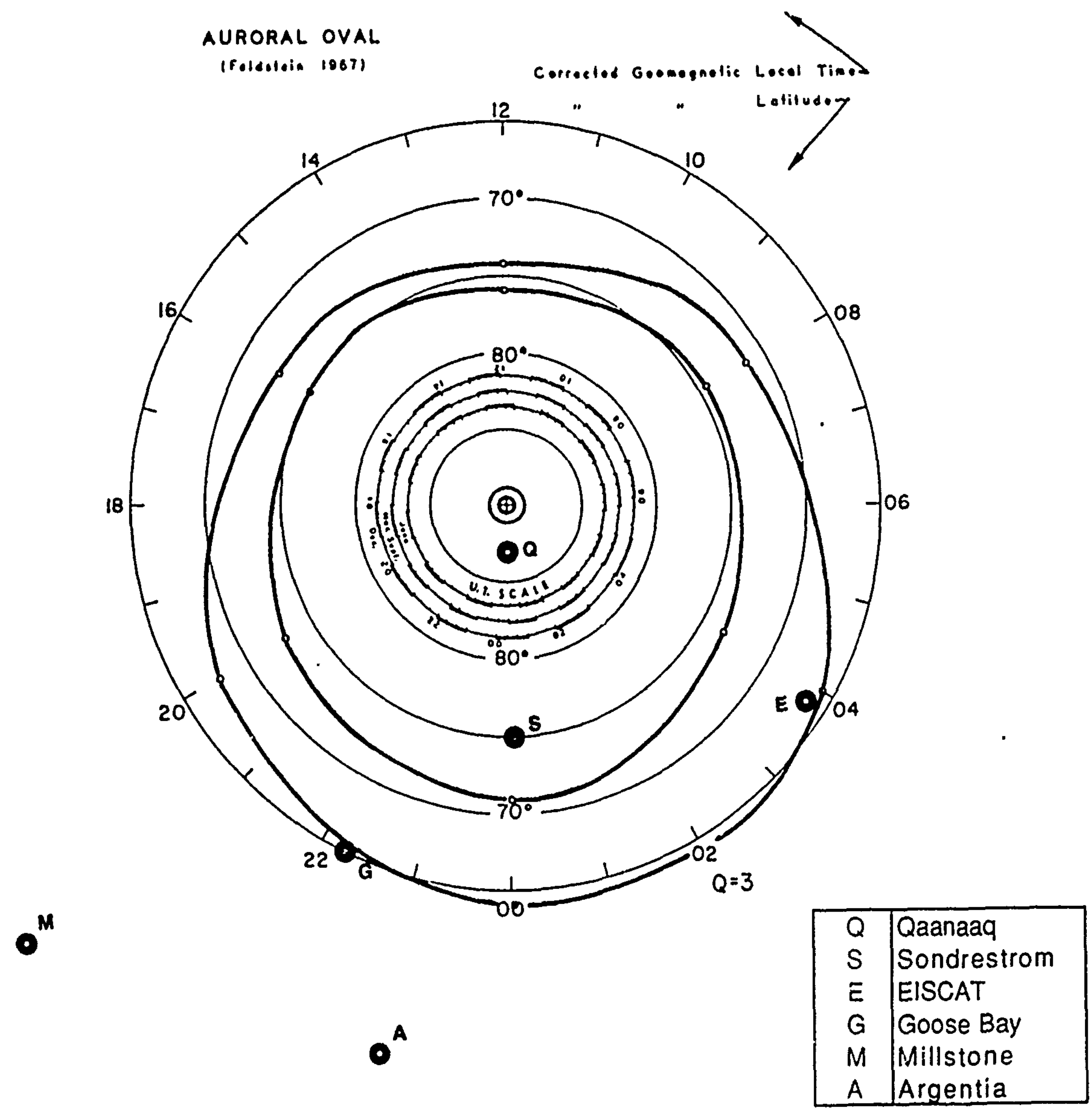


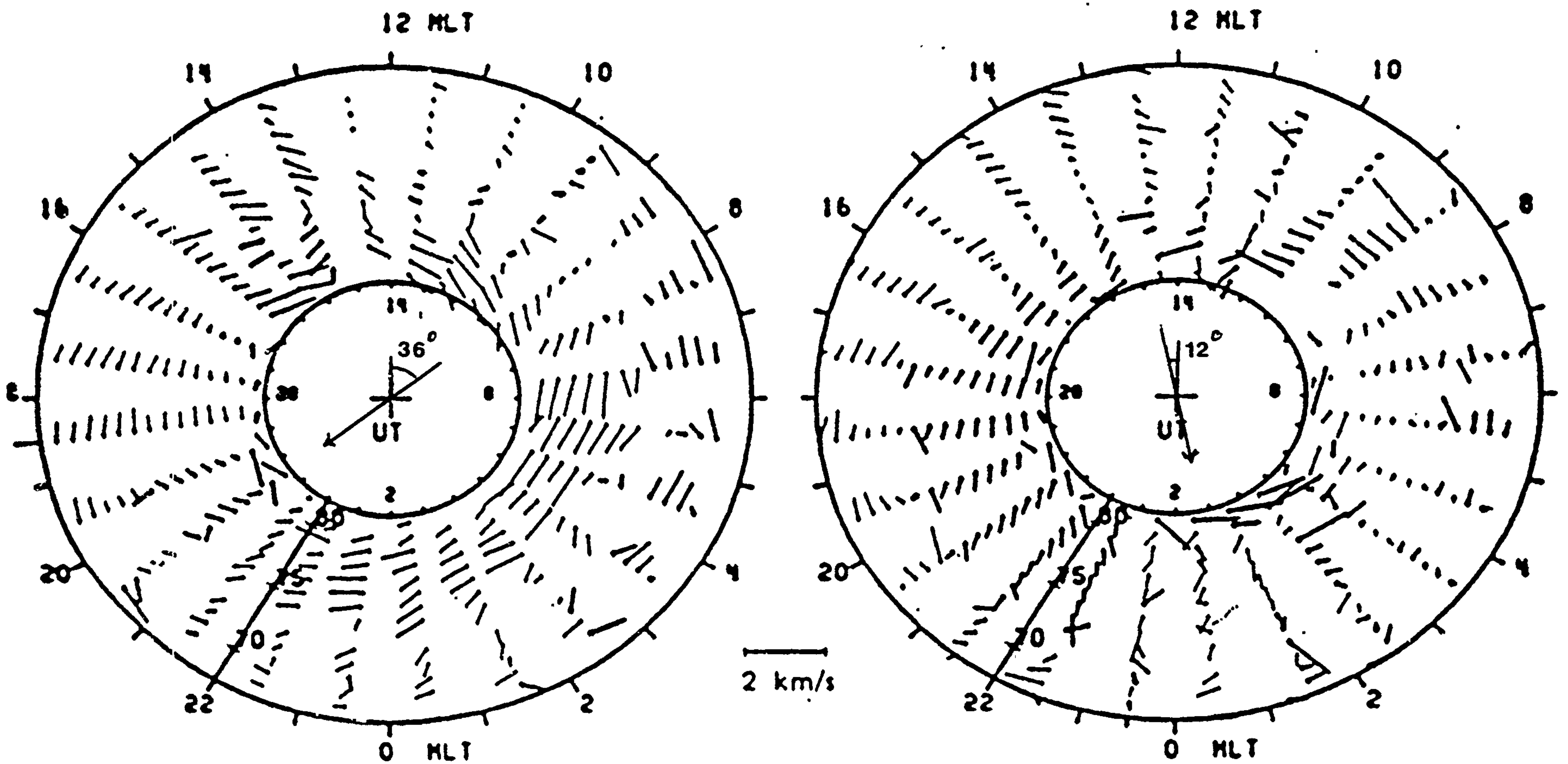
Figure 5. Relative locations of stations for Sondrestrom/Qaanaaq magnetic midnight (0120 UT June, 0200 UT October). Auroral oval is for moderate (Q = 3) conditions.

Sondrestrom is at 75°N corrected geomagnetic latitude. Figure 5 reveals that the Digisonde probes the polar cap in the midnight sector, the magnetospheric cusp near noon and the poleward portion of the auroral oval at other times. It is therefore in a prime location to study a wide variety of interactions between the magnetosphere, ionosphere and neutral atmosphere, and the effects of the solar wind and IMF on these interactions.

An additional factor contributing to the importance of the Sondrestrom site is the clustering of many other instruments which make measurements complementary to the Digisonde data. These include the incoherent scatter radar (ISR), all-sky-imaging photometers (ASIP), Fabry Perot interferometer (FPI), radio scintillation and TEC measurements based on polar beacons and GPS satellites.

Figure 6 depicts the average ion drifts observed by the Sondrestrom incoherent scatter radar under By positive and negative conditions [private communication; de la Beaujardière]. Drift vectors are plotted as a function of MLT and invariant latitude. These average convection patterns show evidence of the classical 2-cell structure, with antisunward flow in the polar cap, and sunward return flow at lower latitudes. A convection reversal is evident for most local times, and for both By conditions. The latitude of the reversal varies with By. For By positive conditions, the polar cap flow is shifted into the morning sector, whilst it is shifted towards the dusk sector for By negative. The arrow in the center of each plot indicates the average drift direction measured by the Digisonde at Qaanaaq [Cannon et al., 1990].

The field of view of the Digisonde is much smaller than that of the IS radar, and covers about 4° of latitude (400 km) as indicated in Figure 6. This figure reveals several important features to be expected in the Digisonde drift measurements. i) The Digisonde will often lie close to the convection reversal, and therefore velocity



(a) B_y POSITIVE

(b) B_y NEGATIVE

Figure 6. Average of ion drifts measured by the Sondrestrom radar, for B_y positive and negative. Arrows at center of plots depict average drift directions from Qaanaaq. Note the latitude scale near 22 UT gives an indication of the 4° Digisonde viewing area centered at 75° invariant latitude.

shears may have to be taken into account. ii) Average velocities of 1 km/sec are to be expected, th efore the instantaneous velocity will often exceed 1 km/sec. iii). For certain times of day, the drifts have different directions depending on By. The drift measurements may therefore permit the sign of By to be deduced for those times.

2.0 THE DIGISONDE INSTALLATION

During June 1989, personnel from both the University of Lowell and the Geophysics Laboratory deployed a DISS system at Sondrestrom, Greenland (50.94° W, 66.98° N) approximately one mile from the Incoherent Scatter Radar site. Figure 7 provides a topographical representation of the DISS system in relation to the ISR, transmit antenna and receive antenna array. Figure 8 provides a detailed sketch of the receive antenna array with respect to its dimensions and orientation.

Upon completion of the DISS deployment, a phase calibration was performed on the Antenna Switch, cabling and the seven receive antenna preamplifiers using the new card 40B drift calibration scheme. Figure 9 presents the calibration set-up used for the drift calibration scheme. Due to the relatively long round trip distance (approximately 2,700 feet) of the calibration cabling, the calibration was conducted in three frequency steps: 0.5 to 8 MHz, 7 to 13 MHz and 12 to 17 MHz switching an in-line attenuator from 20 dB to 10 dB and 0 dB, respectively, to adjust for the different transmission losses in the given frequency intervals. Inspection of the test data confirmed proper DISS system operation.

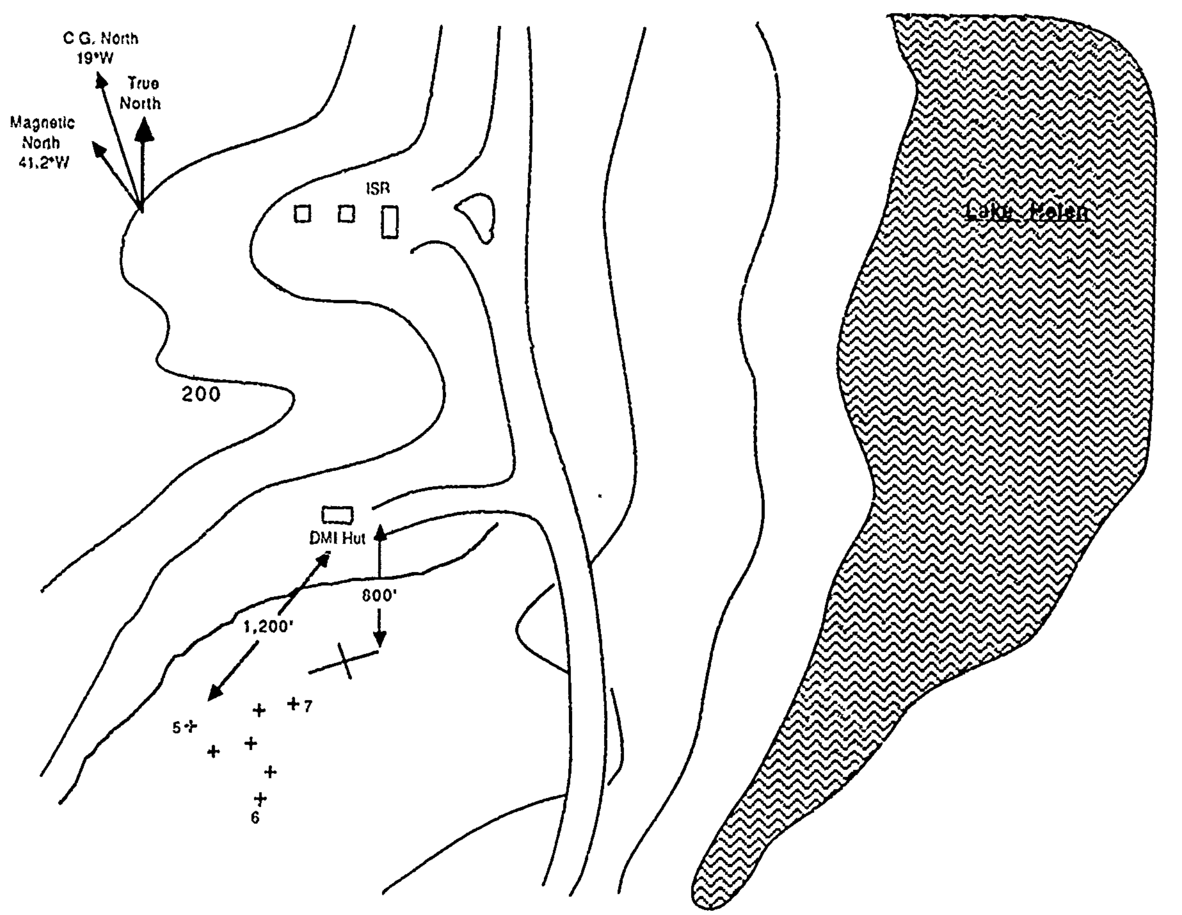
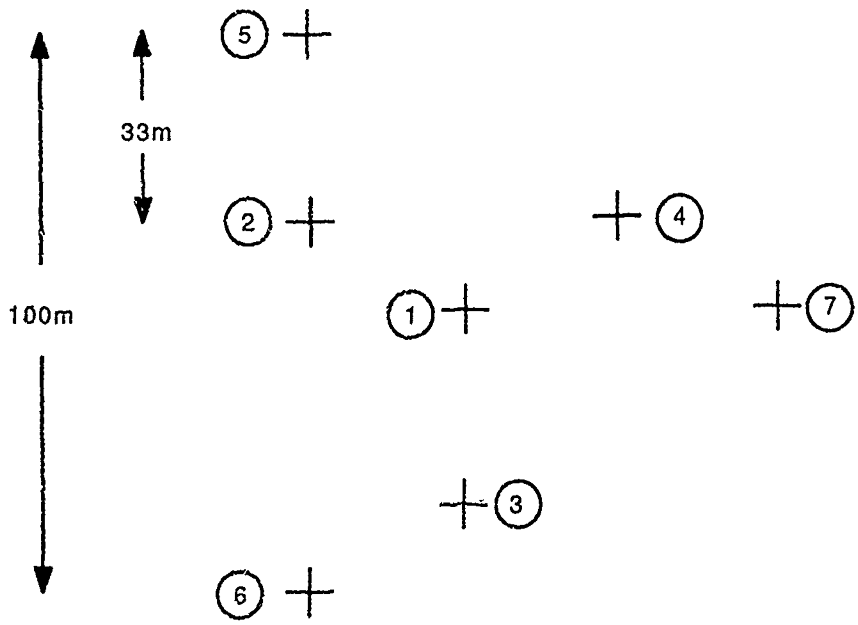
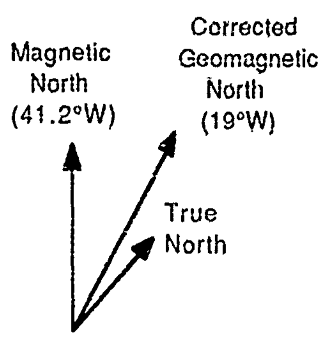


Figure 7. Sondrestrom AN/FMQ-12 Topographical Layout



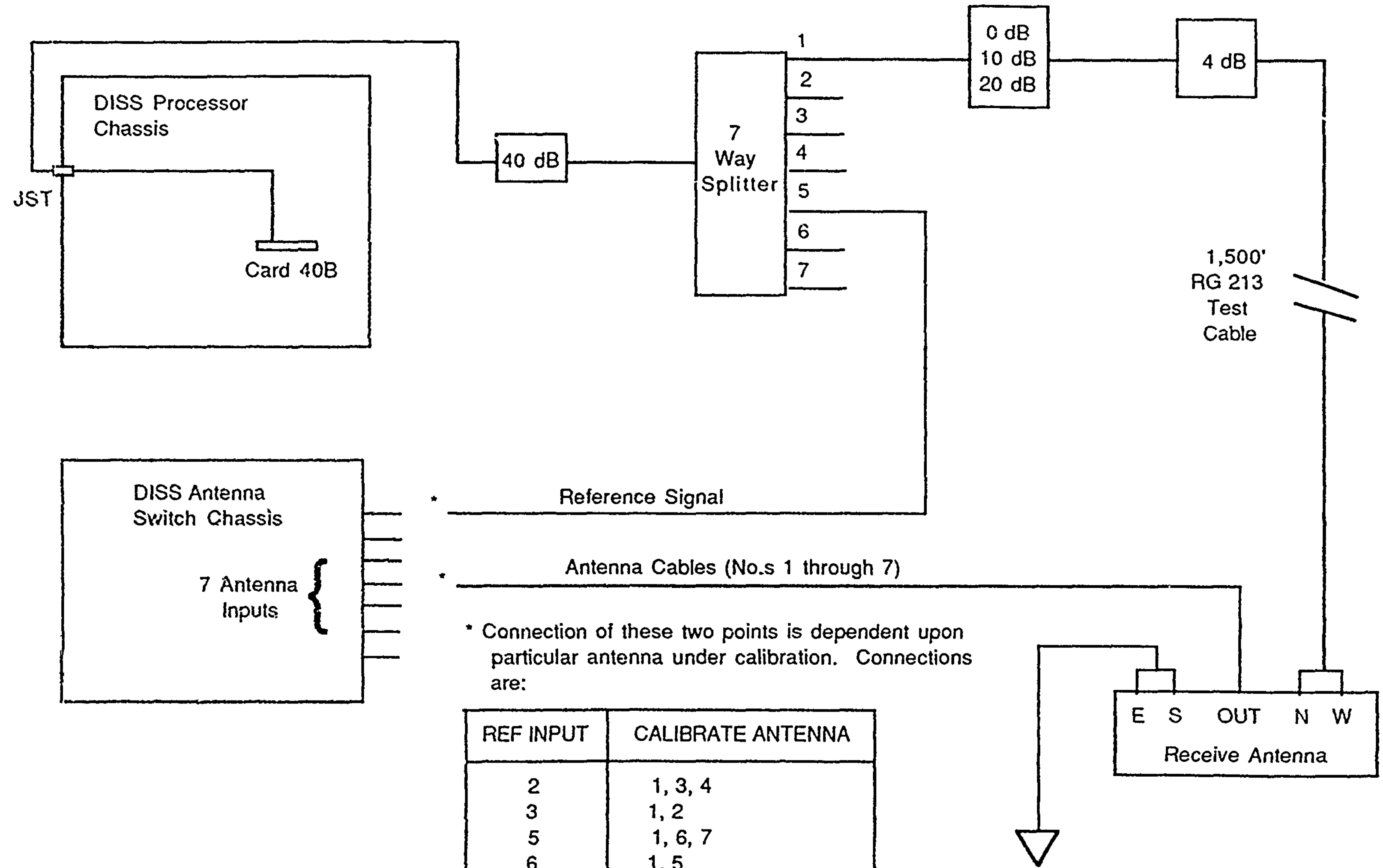


VERTICAL ALIGNMENT

ANTENNA	HEIGHT*
7	0
6	-5'8"
5	-1'9"
4	-3'7"
3	-2'11"
2	-5'11"
1	-5'3"

* Negative sign indicates height below reference antenna (7).

Figure 8. Sondrestrom Receiver Antenna Array



* Connection of these two points is dependent upon particular antenna under calibration. Connections are:

REF INPUT	CALIBRATE ANTENNA
2	1, 3, 4
3	1, 2
5	1, 6, 7
6	1, 5

Figure 9. Drift Calibration Test Set-Up

3.0 JULY 1989 CAMPAIGN

Following deployment of the system at Sondrestrom, an experimental campaign was undertaken in July 1989. This campaign was directed at studying the slant-E condition sometimes observed in the polar cap under magnetically active conditions. Unfortunately, no slant-E conditions were observed, however, drift data were continuously obtained for a five-day interval between 7-11 July 1989, and the campaign provided the opportunity to perform further extensive tests of the Digisonde system, and to conduct drift measurements [Buchau et al., 1988].

Magnetic conditions during the 7-11 July interval ranged from very quiet to moderately active. Table 1 lists the preliminary Kp values for the campaign period.

Under most conditions, the incoherent scatter radar (ISR) would have been used to make drift measurements for comparison with Digisonde data. This is a key aspect of the Digisonde verification process. Unfortunately, the ISR was not available in July due to maintenance and upgrade operations.

The Digisonde was found to interfere with local HF communications on several frequencies. After the campaign, the drift mode was switched off. In the future, a software fix will be devised, preventing the Digisonde from selecting the communications frequencies.

Table 1. Preliminary Kp Values

Date	Planetary Geomagnetic K-Values							
	00 - 03	- 06	- 09	- 12	- 15	- 18	- 21	- 24Z
7/11/89	2	1	2	2	2	3	2	1
7/10/89	2	3	3	3	3	3	2	3
7/9/89	2	3	2	2	2	2	2	2
7/8/89	1	1	2	2	2	2	1	1
7/7/89	2	3	3	2	2	2	2	2

4.0 ARTIST VALIDATION

The labor intensive ionogram scaling and evaluation required by conventional ionosondes has been replaced in the Digisonde by automatic techniques. The Automatic Real Time Ionospheric Scaling Technique (ARTIST) developed by ULCAR [Reinisch and Huang, 1983] is a PC-based system which determines values for the most important parameters from an ionogram, including foE, foF1 and foF2.

Operation of the ARTIST system is always tested at the installation of a new sounder. The results of this validation for Sondrestrom are presented below.

The ARTIST scaling was tested for a period of 24 hours between Day 89188, 13 UT to Day 89189, 13 UT. Ionograms were recorded every 15 minutes during this interval, which was magnetically very quiet and there was very little spread-F on the ionograms. The values of foE, foF1 and foF2 from manual scaling of the 97 ionograms were compared with the ARTIST values.

Figure 10 indicates the differences between the manual and ARTIST values. For all three critical frequencies, 70% of the differences are less than 0.2 MHz. The maximum foE error was 0.6 MHz and 1.4 MHz for foF2. In 24 cases, the ARTIST could not find an unambiguous value for foF1, although values were obtained by a trained operator. In these cases, the error was set to 1.9 MHz (for negative Doppler shifts) or 2.0 MHz (for positive Doppler shifts).

These results indicate that the ARTIST program is working normally, and generally produces good results.

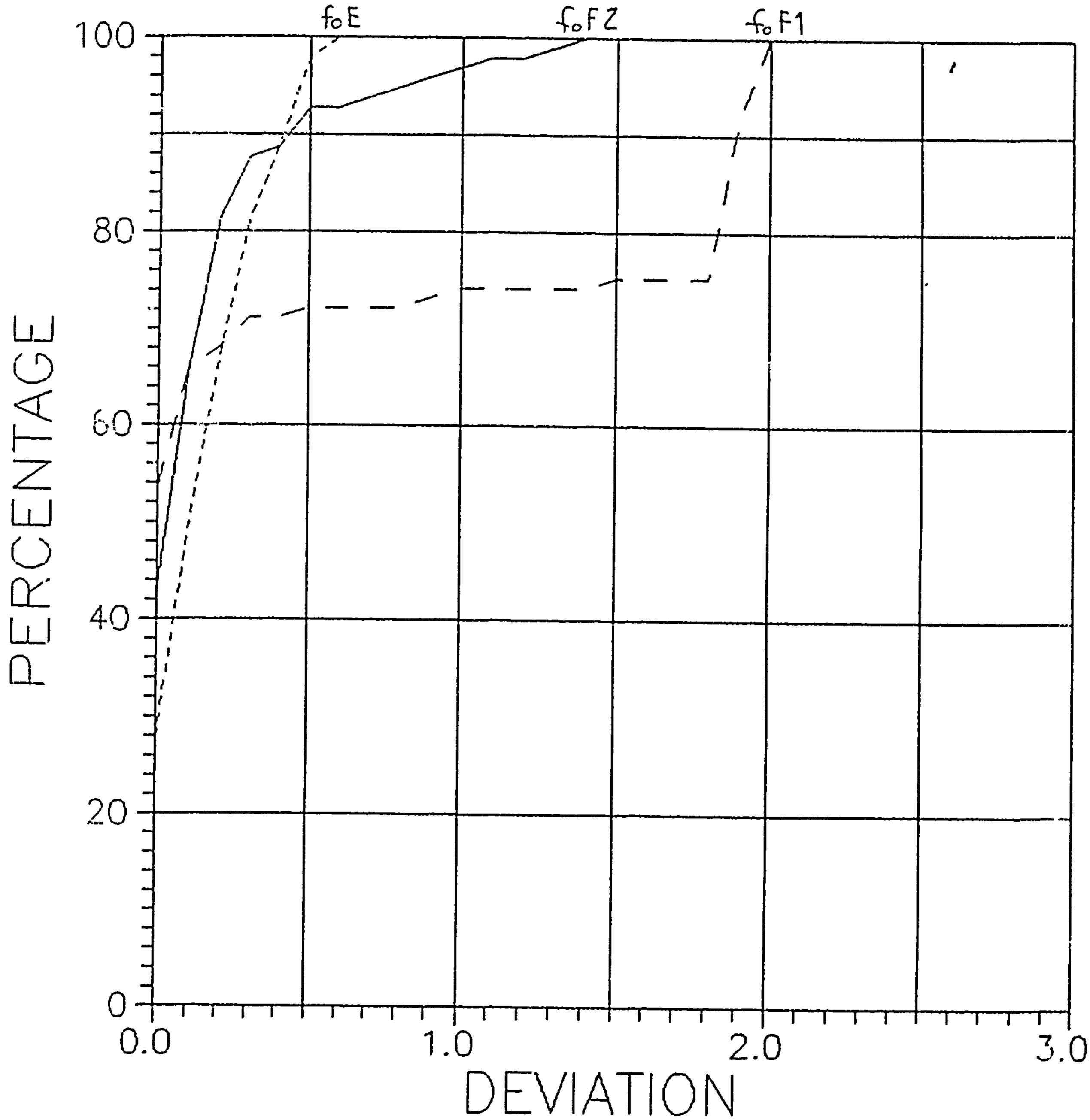


Figure 10. Comparison of manually-scaled to ARTIST-scaled foE, foF2 and foF1 values; Sondrestrom, Greenland; Day 89188, 1300 UT to Day 89189, 1300 UT.

5.0 DRIFT DATA

The drift data obtained at Sondrestrom during the period 89188 - 89192 is illustrated in Figure 11. In summary, the drift directions are generally as expected from the foregoing discussions. In the midnight sector, the drifts are generally antisunward, as expected for polar cap flows under Bz southward conditions. Around 06 UT, the station passes through the convection reversal into a region of sunward (eastward) auroral flow. This remains strongly eastward until the noon sector when the direction switches through northward to strongly westward. In the late afternoon (18 UT) the convection reversal is crossed again, as Sondrestrom re-enters the polar cap. These changes are fairly abrupt in the data of Figure 11. In only one case, (Day 188, 18-24 UT) there is no clear transition from auroral to polar cap flow.

Other corroborative measurements are required to interpret the data fully. For example, the polar cap flows are not perfectly antisunward. Cannon et al. [1990] have determined that polar cap flow directions measured at Qaanaaq vary with IMF By in accordance with IMF-dependent changes in the convection pattern such as those presented by Heppner and Maynard [1987]. Similarly Figure 6 revealed that the polar cap expands into the dusk (dawn) sector for By -ve (+ve), therefore the exact times of crossing the convection reversal are expected to vary with By.

The drift speeds also varied dramatically during the five day period plotted in Figure 11. There is no dependence on time of day, although both the horizontal and vertical speeds measured in the polar cap tend to be larger than those in the auroral return flow. There is also no clear dependence on magnetic activity as defined by Kp.

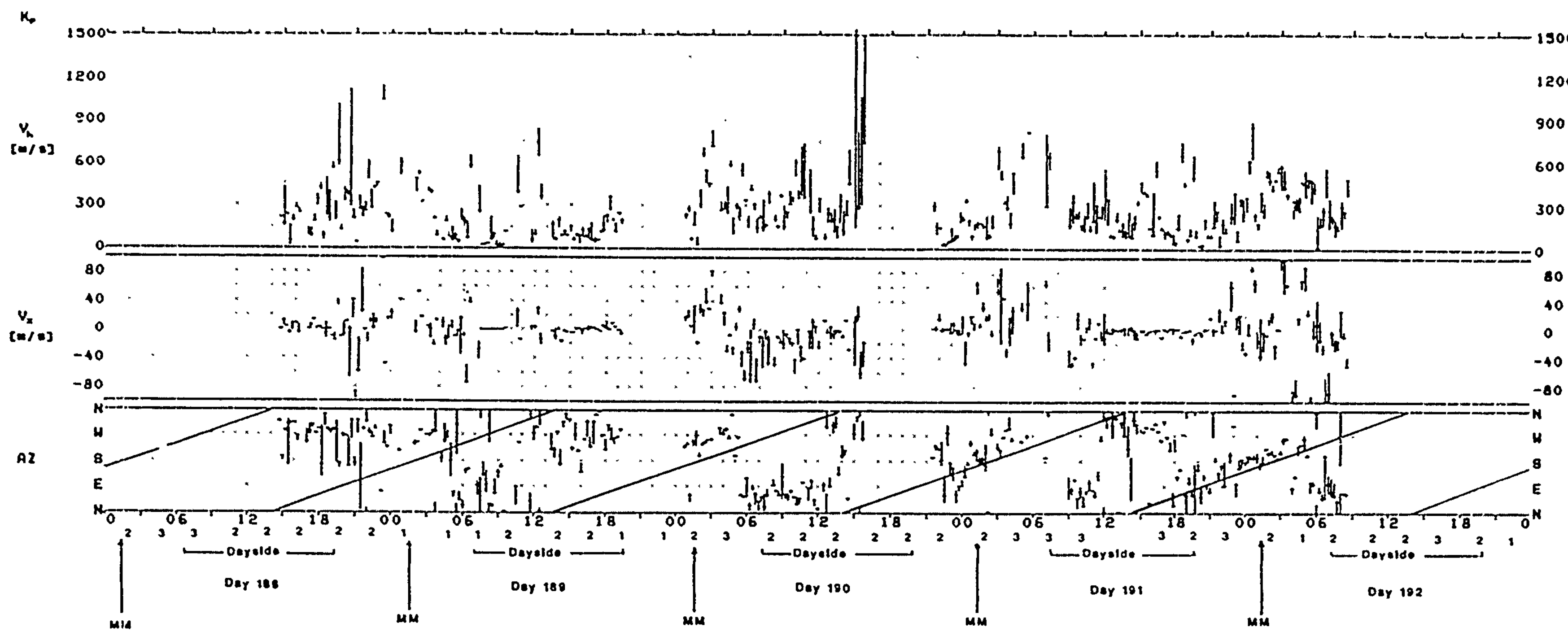


Figure 11. Sondrestrom Drift Data, Day 89188 to Day 89192

The most readily available corroborative data are the drift data from Qaanaaq (Figure 12). Qaanaaq is always inside the polar cap, and the nature of these measurements provides a strong indication of IMF conditions. The oblique lines plotted in Frame C of Figure 12 indicate the antisunward drift direction. The preliminary Kp indices are shown along the lower axis of the figure, and they vary from 1 to 3. The drift directions tend to be close to antisunward for Kp = 3, while there is much more variation for lower Kp. Figure 13 illustrates this relationship more succinctly by plotting the deviation from the antisunward direction against Kp. The higher drift speeds also tend to be associated with higher Kp, as illustrated in Figure 14. This relationship suggests that the highest drift speeds are associated with small deviations from the antisunward direction. Figure 15 confirms this relationship; however, the obvious corollary is not true, and the smallest deviations do not necessarily give large speeds.

Since Sondrestrom and Qaanaaq are at approximately the same corrected magnetic local time (Figure 5), a polar plot in corrected magnetic coordinates provides an interesting opportunity to explore the large scale features of convection for that magnetic longitude. Figure 16 depicts the drift velocities observed at Sondrestrom and Qaanaaq as a function of CGLT for the 24 hour period between 06 UT Day 89191 and 0545 UT Day 89192. This was one of the most active intervals of the entire data set, according to the Kp index, and data from Sondrestrom and Qaanaaq were available almost continuously.

Several interesting features emerge from examination of Figure 16 (note that UT ~ CGLT + 2 hours). At the start of the interval, the Qaanaaq drifts diverge from the antisunward direction, becoming almost sunward by 09 CGLT, suggesting that the IMF Bz component becomes northward. The Sondrestrom drifts are very variable during this interval, though sunward flows predominate

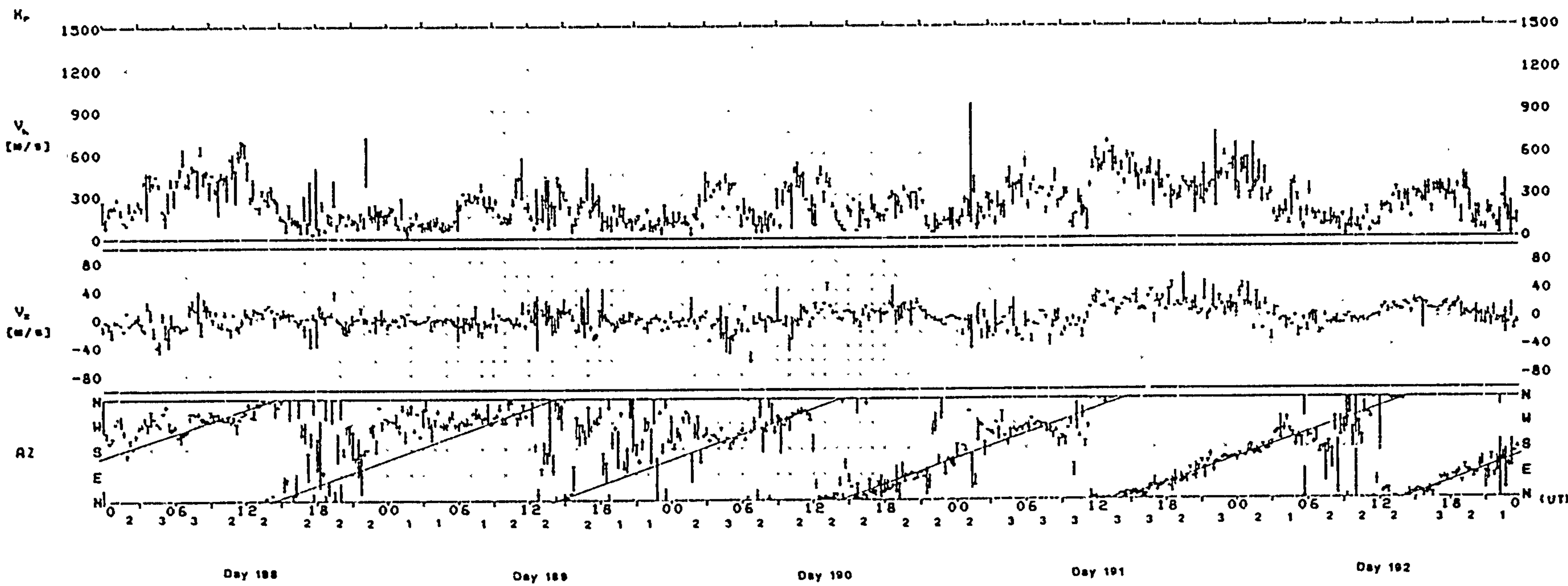


Figure 12. Qaanaaq Drift Data, Day 89188 to Day 89192

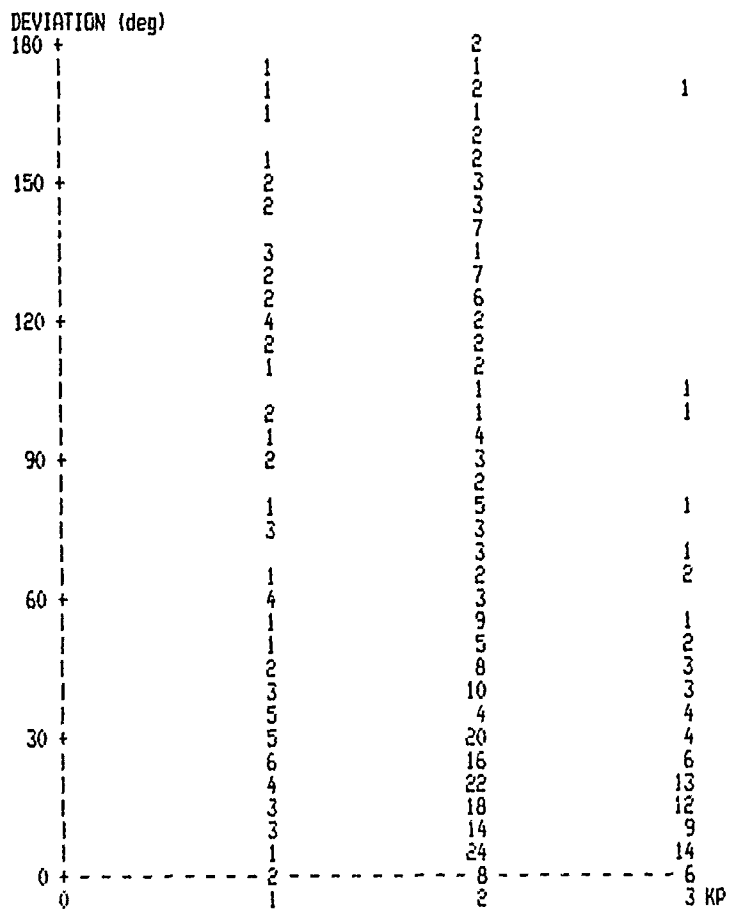


Figure 13. Deviation from the antisunward direction against Kp; Qaanaaq, Greenland; Day 89188, 1200 UT to Day 89192, 1200 UT. Numbers represent frequency of occurrence.

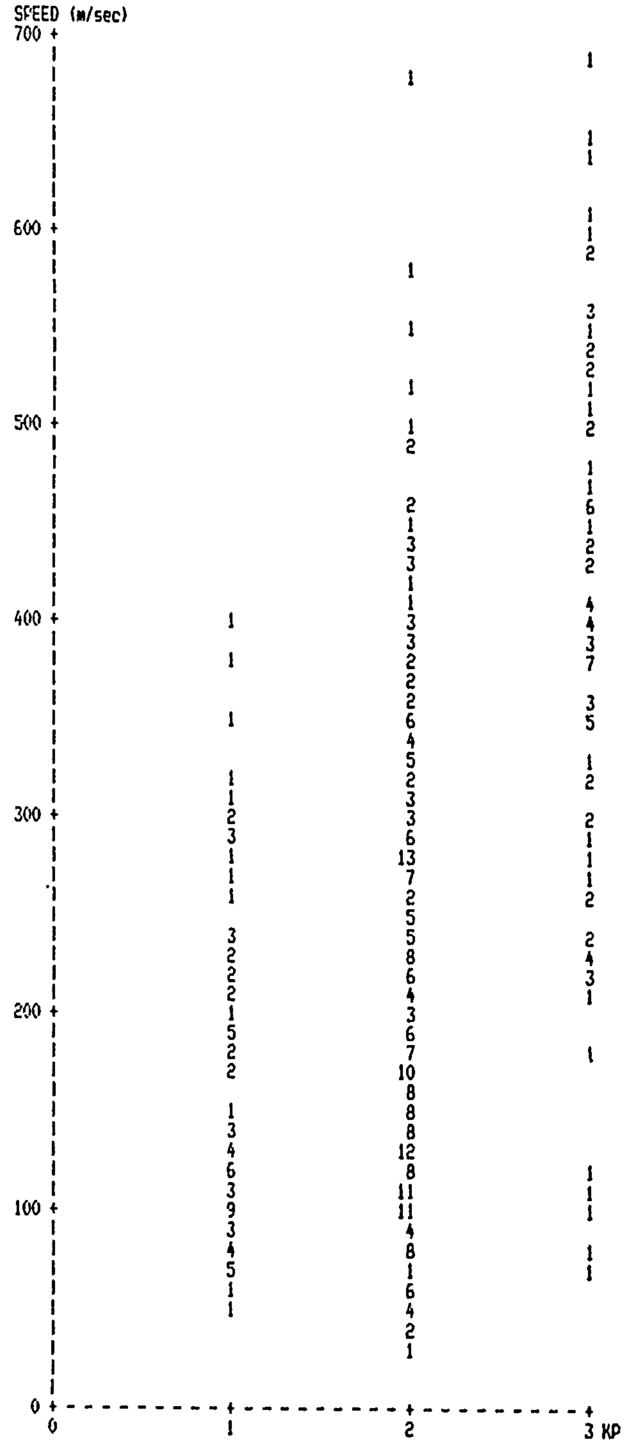


Figure 14. Relationship of drift speeds to Kp; Qaanaaq, Greenland; Day 89188, 1200 UT to Day 89192, 1200 UT. Numbers represent frequency of occurrence.

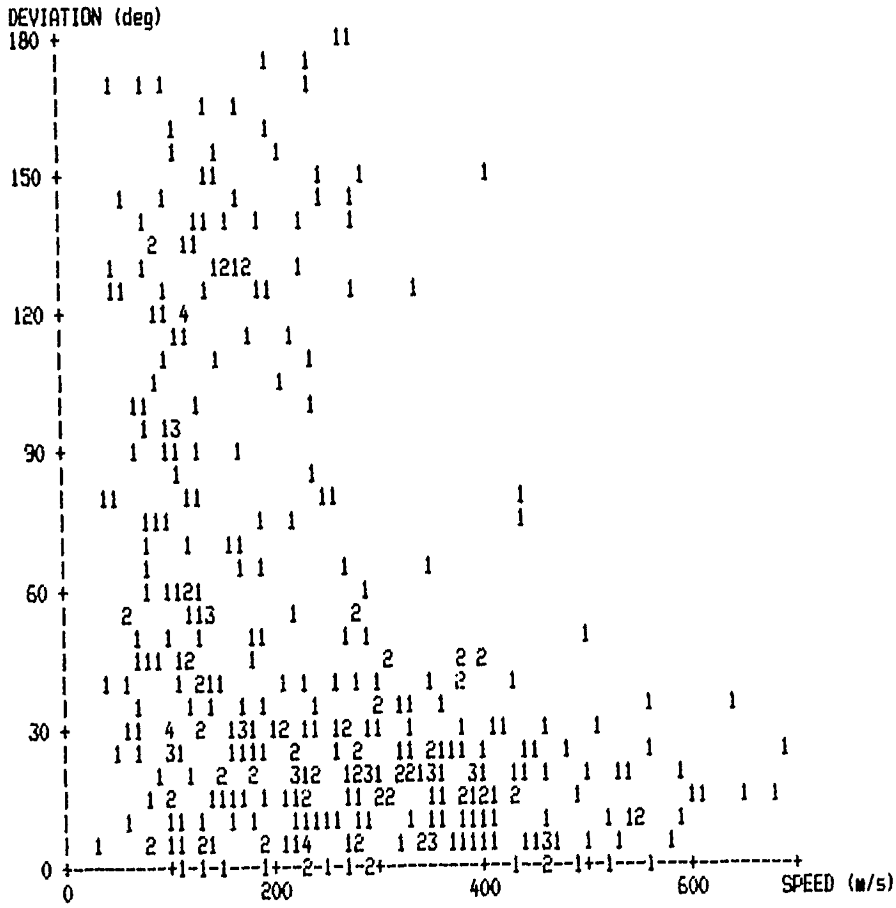


Figure 15. Relationship of antisunward direction to drift speed; Qaanaaq, Greenland; Day 89188, 1200 UT to Day 89192, 1200 UT. Numbers represent frequency of occurrence.

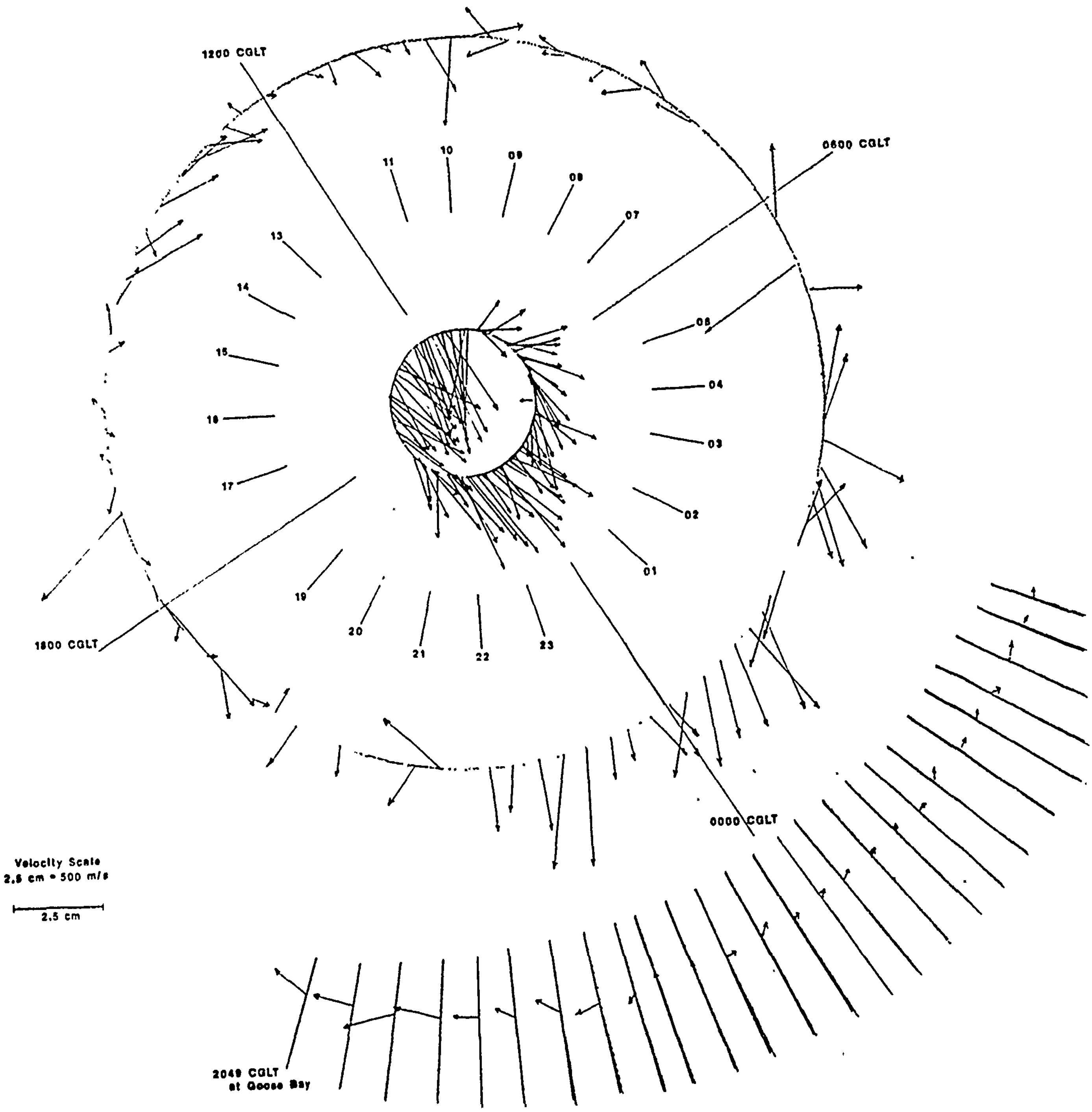


Figure 16. Observed drift at Sondrestrom, Greenland and Qaanaaq, Greenland as a function of CGLT; Day 89191, 0600 UT to Day 89192, 0545 UT.

from about 07 CGLT. At 0915 CGLT, the Qaanaaq flows change abruptly to antisunward, with high speeds around 600 ms^{-1}, typical of IMF Bz southward. The Sondrestrom flow also becomes antisunward before 10 CGLT, suggesting that plasma is entering the polar cap rapidly from the dayside.

At Qaanaaq, the drift direction remains antisunward for the entire day, until the last vector plotted at 0545, indicating that the IMF Bz component remained southward until 0545. The Sondrestrom drift variations are more complex. Using the result of Cannon et al. [1988] which is consistent with Heppner and Maynard [1987] for the influence of By on polar cap flows, it is possible to predict the sign of the IMF By component from the Qaanaaq flow direction. On average, positive By leads to deviations of 36° anticlockwise from the antisunward direction: negative By leads to deviations of -12°. Figure 17 depicts the predicted By direction based on the Qaanaaq data. For much of the time, the predictions based on Sondrestrom data (cf. Figure 5) are the same. For example at 03 UT the flow direction changes from approximately southward to strongly south westward, indicating an IMF By change from negative to positive. When IMF data become available in the near future, these predictions will be tested.

Unfortunately software is not yet available for plotting figures such as Figure 16 on a routine basis. Since these plots promise to be extremely useful, the appropriate software will be developed before other days are examined in detail.

The data from the other days promise to be much more difficult to interpret, and contain extended intervals of sunward convection observed at Qaanaaq, suggesting northward IMF. This is corroborated by the lower Kp values for most of the time. Assuming the Digisonde drift data can be validated for northward Bz conditions, these data will be vital for defining convection patterns for Bz

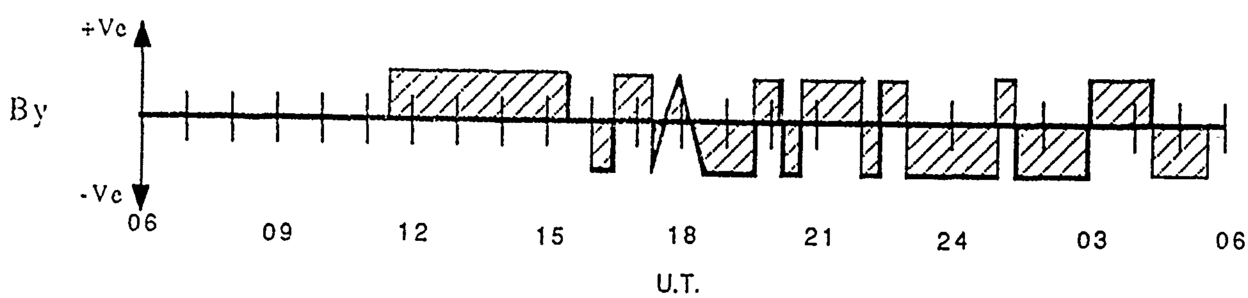


Figure 17. Predictions based on Qaanaaq flow direction; Day 89191, 0600 UT to Day 89192, 0545 UT.

northward. These patterns are currently thought to consist of 2, 3 or 4 cells, although the actual number of cells is debated.

Data from Day 188 18-24 UT are particularly interesting in this respect. The Qaanaaq drifts are mostly sunward, and the Sondrestrom drifts do not contain an abrupt crossing of the convection reversal expected around 19 UT. The observed pattern may possibly be understood in terms of a shrunken polar cap due to the Bz northward and low activity conditions, however, a reliable explanation of these observations requires the examination of more data.

6.0 IONOGRAMS

The Sondrestrom ionograms are of a very high quality. A cursory examination reveals evidence of many interesting features such as polar cap patches, diffuse aurora (spread-F) and auroral arcs (sporadic-E). The ionograms have not yet been examined in detail, but they will be analyzed with reference to the convection velocities discussed above, in order to obtain a more complete picture of the high latitude ionosphere.

7.0 CONCLUSIONS

1) The new Digisonde DGS 256 installed at Sondrestrom, Greenland during June 1989 is fully operational. The system has been calibrated and provided high quality data for a 5-day interval between 7-11 July 1989.

   The drift mode interfered with local communications on certain frequencies and therefore had to be switched off. The drift mode operation will be modified to avoid the most important communication frequencies. Ionograms have been collected during much of the interval from July - October 1989, but the data are still at Sondrestrom, awaiting shipment to AFGL for analysis.

2) Quantitative validation of the Digisonde drifts by comparison with ISR data was again thwarted. This validation is a matter of utmost urgency and will be completed as soon as possible (around November 1989).

3) The drift and ionograms from Sondrestrom generally show the kind of features expected. In particular, the instrument samples different parts of the convection pattern, including the polar cap, at different times of day.

   Data from other stations will provide further details of convection behavior. Qaanaaq, Goose Bay and Argentia will be examined at the first opportunity. Eventually, drift data from all the AF Digisondes will be used as inputs to the AMIE (Assimilative Mapping of Ionospheric Electrodynamics) technique of Richmond and Kamide [1988] to derive global convection patterns.

8.0 REFERENCES

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